Compact and efficient fibre-to-waveguide grating couplers in InP-membrane

F. Van Laere [(1)], M. Ayre[(2)], D. Taillaert[(1)], D. Van Thourhout[(1)], T.F. Krauss[(2)], and R.Baets[(1)]

[(1)] Ghent University – IMEC, Department of Information Technology (INTEC), St.-Pietersnieuwstraat 41, 9000 Ghent – Belgium

Contact : frederik.vanlaere@intec.ugent.be

[(2)] School of Physics and Astronomy, University of St. Andrews, St. Andrews, Fife, KY169SS

High coupling losses between nanophotonic waveguides on chip and optical fibre are a key problem in optical communication networks. Grating couplers made in high vertical index-contrast material (e.g.SOI), can be an effective solution. However, the InP-material system, needed for active optical functions, has a low index-contrast.

In this paper, we describe the design and fabrication of compact (10 μm) and efficient grating couplers in InP. A high vertical index-contrast is achieved by wafer bonding. Coupling efficiencies of 30% were measured on first fabricated components. More complex structures show theoretical efficiencies above 80%.

Introduction

The large deviation in dimensions between an optical fibre mode and an optical waveguide mode causes high insertion losses and high packaging costs. Several solutions have been proposed to address this issue. Typically, some kind of tapered structure is used [1]. We want to explore the use of grating couplers to tackle the problem. Light is then vertically coupled from fibre to waveguide, by means of a grating. In this way, the coupling with the outside world can occur everywhere on the chip (and not only at the edges), allowing for wafer-scale testing. In [2], compact grating couplers in SOI (Silicon-on-Insulator), with coupling efficiencies of 25% were reported. Because of the high vertical index contrast of this material, strong gratings with small coupling lengths can be made. However, SOI is not very suitable for active components. For telecom applications, InP is the material of interest, but the easy transfer of existing designs in SOI is inhibited by the too low vertical index contrast of conventional InP-heterostructures.

By applying wafer bonding technology, we can modify the index-contrast of an InP-based layer structure. In this paper, we report the successful fabrication of efficient and compact grating couplers in InP, based on this technology.

High vertical index-contrast by wafer bonding

A possible definition of "bonding" is "joining of two pieces of material". We focus on indirect bonding, using the polymer BCB (BenzoCycloButene) as a bonding agent. BCB is a low-k dielectric, which is chemically inert and resistant to chemical etching. The bonding can be described as follows (Fig. 1). Gratings and waveguides are defined by e-beam lithography, the pattern is transferred into a Fox-14 (flowable oxide) hard mask by RIE, and finally etched to a depth of 120 nm into an InP-heterostructure by RIE (Fig. 1b). BCB is spun onto a GaAs host-substrate (Fig. 1c), and the InP-heterostructure (with the grating) is placed upside down on the host-substrate (Fig. 1d). Hence, the grating is at the bottom side. After BCB-curing for an hour at 250 degrees in a N_2 environment, the substrate of the grating sample has to be removed, first mechanically, then chemically (Fig. 1e). Finally, the InGaAsP etch-stop layer is removed (Fig. 1f). The result is a thin high index InP-layer, sandwiched between BCB and air (both of low refractive index). More details on BCB-bonding can be found in [3].

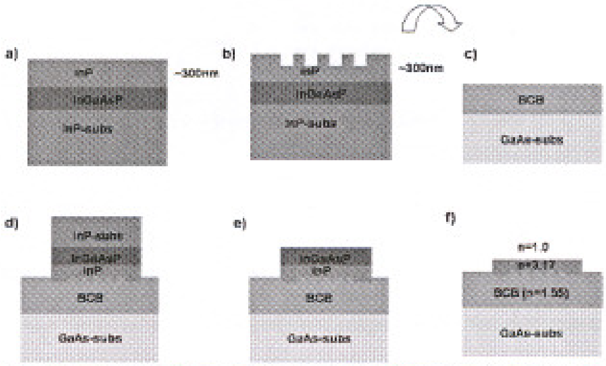

Figure 1. Bonding principle. (a) InP-heterostructure. (b) Definition and etching of the grating and waveguides. (c) Spin-coating BCB. (d) Bonding of grating-sample on the host-substrate. (e) Removing the InP-substrate. (f) Removing the etch-stop layer.

Design

For the design of the grating couplers, we use CAMFR (an eigenmode expansion tool). All simulations are for TE-polarisation. To avoid reflection back into the waveguide, we have to break the symmetry. Thus we tilt the fibre, by 10 degrees (near vertical coupling, in stead of vertical). The optimized parameters are: period=660 nm, filling factor=0.5, etch depth=120 nm, BCB-thickness 1.18 µm. By applying an extra layer (e.g. Al_2O_3 with optimized thickness) on top of the structure, the coupling efficiency can be increased. The maximum coupling efficiency is 59% and the 1dB bandwith is around 50 nm. The field profile for an optimized structure is shown in Figure 2 and the coupling efficiency as a function of wavelength in Figure 3.

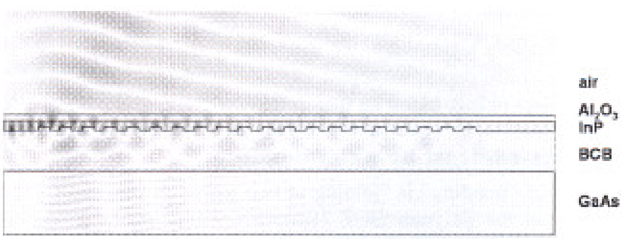

Figure 2. Field profile of a bottom-grating coupler.

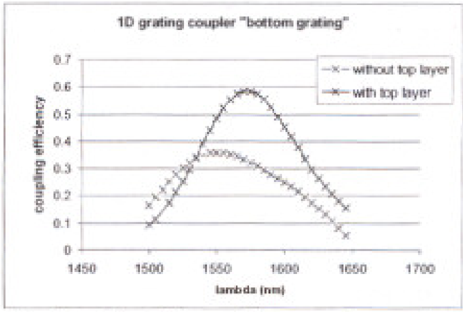

Fig.3 Coupling efficiency of a bottom-grating coupler.

The coupling efficiency can be further increased by adding a bottom reflector (coupling efficiency of 80%) and by varying the width of the grating teeth (coupling efficiency more than 90%)

Results and discussion

In a first fabrication run, uniform grating couplers are fabricated. A cross-section of a fabricated 1D-grating coupler is shown in Fig.3. In order to measure the performance of the coupler, a fibre connected to a tunable laser, is positioned above the input grating at a 10 degrees angle, and another fibre, connected to a power detector, at the output grating. Assuming that input and output grating are the same, and taking losses in the measurement setup into account, the coupling efficiency can be estimated. First measurements are done without extra top layer, and afterwards a 240 nm Al_2O_3 is deposited. The results are shown in following graphs. The measured coupling efficiency without Al_2O_3-layer for the 1D-grating is approximately 19%. This value is increased to 30% when applying an extra top layer.

Fig.4 Cross-section of a 1D-grating coupler.

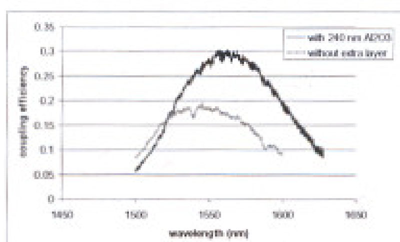

Fig. 5 Measured coupling efficiency of the fabricated coupler.

The deviation between theory (59% coupling efficiency) and experiment (30%) is caused by a slightly other BCB-thickness than targeted. The target thickness was 1.18 µm, while we measured a BCB-thickness of 1.308 µm from the SEM-image. For the parameters deduced from this image, the theoretical coupling efficiency is 48%. Another part of the deviation may be caused by roughness induced through the etching.

Conclusions

We have presented the design and fabrication method of compact fibre-to-waveguide couplers on InP-membrane. We have demonstrated 30% coupling efficiency on first fabricated structures.

Acknowledgements

Part of this work was supported by the European Union through the IST-FUNFOX project. F. Van Laere thanks the Flemish Institute for the industrial advancement of scientific and technical Research (IWT) for a specialization grant. J. Schrauwen is acknowledged for making a FIB cross-section.

References

[1] T. Shoji et al., "Low loss mode size converter from 0.3 μm square Si wire waveguides to simglemode fibres", Electronics Letters, vol. 38, pp. 1669-1670, 2002.

[2] W. Bogaerts et al., "Basic structures for photonic integrated circuits in Silicon-on-insulator", Optics Express, vol. 12(8), pp. 1583-1591.

[3] I. Christiaens et al., "Thin-film devices fabricated with BenzoCycloButene adhesive wafer bonding", Journal of Lightwave Technology, vol. 23(2), pp. 517, 2005.

POLYTECH.MONS

ACADÉMIE UNIVERSITAIRE WALLONIE-BRUXELLES

Service d'Electromagnétisme et de Télécommunications

2005 IEEE/LEOS Symposium Benelux Chapter Proceedings

Supported by:

FNRS
BELSPO (IAP V-18)

Editors :
P. Mégret, M. Wuilpart, S. Bette, N. Staquet

December 1-2, 2005
Faculté Polytechnique de Mons
Belgium

ISBN: 2-9600226-4-5
Faculté Polytechnique de Mons
Service d'Electromagnétisme et Télécommunications